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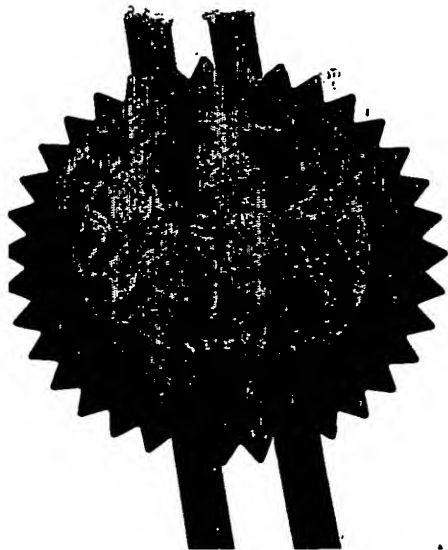
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1. Your reference

P171-GB

2. Patent application number

(The Patent Office will fill in this part)

0311676.1

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3. Full name, address and postcode of the or of each applicant (*underline all surnames*)

1... Limited

St John's Innovation Centre

Cowley Road

Cambridge CB4 0WS

Patents ADP number (*if you know it*)

If the applicant is a corporate body, give the country/state of its incorporation

England

811 3870001

4. Title of the invention

CERAMIC ACTUATOR, METHOD OF MANUFACTURING AND USES THEREOF

5. Name of your agent (*if you have one*)

Akram K. Mirza

"Address for service" in the United Kingdom to which all correspondence should be sent (*including the postcode*)

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Patents ADP number (*if you know it*)

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Country

Priority application number
(*if you know it*)

Date of filing
(day / month / year)

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

Date of filing
(day / month / year)

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (*Answer 'Yes' if:*

YES

a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or

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See note (d))

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| Drawing(s) | 4 |



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11. I/We request the grant of a patent on the basis of this application.

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Date 21-MAY-2003

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Akram K. Mirza

01223-422290

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**CERAMIC ACTUATOR, METHOD OF MANUFACTURING
AND USES THEREOF**

FIELD OF THE INVENTION

5 The present invention relates to novel electro-active actuators, their manufacturing and use in devices such as loudspeaker systems for portable electronic devices.

BACKGROUND OF THE INVENTION

10 It is known to construct a rotary device from a curved piezoelectric element shaped as arc around an axis. Such devices are for example described in the international published patent application WO-02/078053 and WO-03/001841.

15 In the commonly-owned published international patent application WO-03/001841, which is incorporated herein by reference, there are described various devices and methods to generate sound comprising a support on which is mounted an electro-active actuator, which is in turn coupled to an
20 area-extensive section of the case of the device, which section of the case acts as the sound generating element of a loudspeaker. In embodiments illustrated therein the sound generating element is driven in operation by an electro-active actuator preferably acting upon an edge of the sound
25 generating element. The actuator described is a flat ceramic bender curved into an almost tubular shape. This arcuate or C-shaped actuator generates a motion that is partly rotary in nature. For some applications, however, it is desirable to minimize the amount of rotary motion to the
30 extend possible.

It is therefore the purpose of the present invention to provide an electro-active actuator capable of generating a

linear motion for use in devices such as loudspeakers for mobile phones etc.

SUMMARY OF THE INVENTION

5 Accordingly, in a first aspect the present invention provides a ceramic electro-active actuator comprising an arcuate middle section extending tangentially into two essentially straight end sections, similar to the shape of the letter "U".

10 The actuator is preferably cast or formed from one sheet of ceramic precursor material, such as "green tape". However at least every second of the electrodes required to pole or drive the actuator is discontinuous at the borders
15 between adjacent sections. More preferably, both linear sections are electroded and poled in an essentially identical manner, whilst the center electrode is electroded and poled differently from the other sections.

20 In a preferred embodiment the length of the middle section equals essentially the combined length of the straight sections measured in tangential direction. The length referred to is the length of the active, i.e., electroded segment of a section, discounting other passive parts of
25 the sections.

According to a second aspect of the invention, there is provided a method of manufacturing ceramic actuators comprising the step of preparing a three layer pre-cursor
30 sheet with a continuous center electrode and two discontinuous outer electrodes with a layers of pre-cursor electro active material between adjacent electrode layers.

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The discontinuous electrodes are preferable separated by non-conductive gaps at locations that correspond to the transition zones between the sections to be formed at a later forming step, thus being separated into two end and one middle segment.

a preferred variant of the method, an electrically conducting path is established between the end sections of one discontinuous electrode to the middle section of the other discontinuous electrode.

In a preferred embodiment of the method, the pre-cursor sheet is pressed in a mold and subsequently dried and sintered at elevated temperatures to render the pre-cursor material into electro-active material and to give the actuator the desired shape.

According to another aspect of the invention the actuator is used to drive a sound generating element in a portable device, preferably connected to a panel type diaphragm. The actuator is preferably mounted with one extended end section along an edge of the diaphragm with the opposite end being mounted on the housing of the device.

These and other features of the inventions will be apparent from the following detailed description of non-limitative examples making reference to the following drawings, throughout which like parts are designated by like reference numerals and characters.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

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FIG. 1A is a perspective top view of an actuator in accordance with an example of the invention;

FIG. 1B shows a cross section through the actuator of FIG. 1A;

FIG. 1C shows a top view on the bottom face of the actuator of FIG. 1A;

FIG. 2 illustrates the bending deformation of the actuator of FIG. 1;

FIG. 3 illustrate a loudspeaker driven by an actuator as shown in FIG. 1 is a perspective top view of another variant of the novel actuator;

FIG. 4 shows electrode layouts for use in a manufacturing process for an actuator in accordance with the invention; and

FIGS. 5A-C illustrate a tape forming process for use in a manufacturing process for an actuator in accordance with the invention;

DETAILED DESCRIPTION

In FIG. 1, there is shown a perspective view (FIG. 1A), a cross-sectional view (FIG. 1B) and a top view on the bottom face (FIG. 1C) of the novel actuator 10. The main elements of the actuator include a convex curved or arcuate middle section 11. Both ends of the middle section 11 extend continuously in tangential direction into two essentially flat sections 12, 13. The actuator 10 is manufactured from multi-layered ceramic tape 101 with layers of ceramic PZT

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separated by layers of electrodes. The outer (visible) electrodes 102 are split at the transition zone between different section by gaps 103. The flat section 13 forming the bottom face of the actuator carries further contact points. The contact points 104 provide conductive channels (via-fills) 105 to the center electrode 106 and the opposite outer electrode 102, respectively. Placing the contact points 104 on the bottom face is advantageous when using surface mounting to mount the actuator on supporting structures such as PCB boards (see FIG. 3).

In FIG. 2 there is illustrated the deformation of the actuator 20 upon activation by an appropriate voltage applied to the electrodes. The actuator without activation is drawn using solid lines and dashed lines are used to depict the energized actuator. It should be noted that the deformation is drawn out of scale.

Upon activation, the ends of the c-shaped center section 21 perform a rotational movement with a slight contraction around its center of curvature as indicated by the arrows 24, 25. The extended straight sections 22, 23 bend as conventional benders. The distal ends 221, 231 of the actuator perform a very good approximation of a linear motion in vertical direction as indicated by the arrow 26.

In FIG. 3, the actuator of FIG. 1 is shown used as a drive unit 30 to drive a rectangular diaphragm 34 within the housing 35 of a mobile device. The diaphragm is made of transparent polycarbonate. It rests within a recess of the housing so as to be mounted flush with its outer surface.

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The gap between the housing 35 and the diaphragm 34 is sealed off by means of a compliant gasket 36. The gasket 36 prevents the entry of dust or humidity. It is made of Poron (TM), a cellular urethane based sealing material.

5

10

The actuator 30 bridges is surface mounted with a first distal end 301 of the bottom straight section onto a PCB board 31 that carries drive electronics, power supply and other electronic circuitry. The end 302 of the top straight section of the actuator 30 is connected to an edge of the diaphragm 34 via a spacer element 32. The connection is capable of transmitting a force such that in operation the vertical movement of the actuator 30 drives the edge of the diaphragm 34 which in turn generates audible sound.

15

20

The effective length of the straight sections is in part determined by the length over which these section are mounted or connected to spacer element or support. These part of the sections become too stiff to deform as a bender. When considering the active length of a section these parts have to be discounted.

25

Compared to known devices such as described in WO-03/001841, the novel configuration provides an improved sound quality.

30

The novel actuator can be manufactured from ceramic tape material made in accordance with know techniques as described for example by D. Pearce et al in Sensors and Actuators A 100 (2002), 281-286. The components such as PZT powder, binder and solvent are mixed, milled and pressed into flat sheets of the desired thickness.

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The electrodes are screen printed onto the sheet using platinum or silver ink. A specific electrode layout may be used that facilitates the manufacturing and mounting of the novel actuators. This layout is shown in FIG. 4 which depicts the outer, center and inner electrode layer of an actuator with two PZT layers (as shown in FIG. 1).

The outer electrode 41 and the inner electrode 43 which on the actuator will both form outer visible electrodes are split by lines 44 into sections which correspond to the sections to be seen on the finished actuator. The center electrode 42 is continuous but includes smaller blank areas 45. Cross-layer electrical contacts are made at a later stage either through (using a via-fill) or across the outer edges of the areas 45 (using conductive ink or solder). With the electrode pattern and blank areas it is possible to connect electrodes such that an electrically conducting path is established between the end sections of one discontinuous electrode 41 to the middle section of the other discontinuous electrode 43 bypassing the continuous electrode 42.

Hence, in the finished actuator as shown in FIG. 1, the end sections of the outer visible electrode lie on the same potential as the middle section of the inner visible electrode and the end sections of the inner visible electrode lie on the same potential as the middle section of the outer visible electrode. In this configuration, the center electrode is not connected to any section of the outer electrodes.

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Two or more printed sheets are then stacked to form a final bimorph tape. The bimorph ("green") tape is still plastically deformable.

5 A further processing step towards the novel actuator is shown in FIG. 5. In the forming step of FIG. 5, the green tape 50 is placed between the moving part 51 and stationary part 52 of a former or mold (FIG. 5A). The moving part 51 is then pressed downwards into the opening of the
10 stationary part 52 thereby forcing the tape into the desired shape (FIG. 5B). In its final position (FIG. 5C), the moving part 52 has pushed the tape fully into the U-shaped mold.

15 It is worth noticing that the outer contour of the moving part 51 matches the inner contour of the stationary part 52 along the bottom section of the mold essentially corresponding to the curved center section of the finished actuator. However above this section the cross-section of
20 the moving part tapers away from the walls of the mold 51, thus facilitating the removal of the moving part without pushing the tape out of its final position or form.

The tape can be left drying in the former and then removed
25 from it. Then the tape is burned out and sintered at high temperatures (600 to 1200 degrees Celsius). Outer electrodes may be applied after the sintering step.

In a poling step the straight sections (as referred to in
30 FIG. 1) are poled in a direction opposite to the poling direction in the center section.

After the poling the actuator is ready to be mounted onto a

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support and a driving voltage can be applied for example to the center electrode.

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CLAIMS

1. Loudspeaker for audible sound comprising a sound
emitting element mounted onto a support structure and
5 at least one ceramic bender-type actuator being
connected to said sound emitting element and a
support, wherein the actuator comprises an arcuate
middle section extending tangentially into two
essentially straight end sections and wherein the
10 sound emitting element is connected to an end portion
of one of the straight section and the actuator is
mounted with an end portion of the other straight
section onto the support.
- 15 2. The loudspeaker of claim 1 having a compliant sealing
element or elements around the edges of the sound-
emitting element.
- 20 3. The loudspeaker of claim 1 wherein sound emitting
element is a flat or slightly curved transparent
panel.
- 25 4. The loudspeaker of claim 1 wherein the support
structure and the sound generating element are parts
of the outer shell of a portable data handling or
communication device.
- 30 5. Ceramic actuator comprising an arcuate middle section
extending tangentially into two essentially straight
end sections.
6. The ceramic actuator of claim 5 wherein the two
essentially straight sections are parallel to each

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other.

7. The ceramic actuator of claim 5 having an essentially
-shaped cross-section.

5

8. The ceramic actuator of claim 5 wherein the straight
sections are poled in a direction opposite to the
poling direction of arcuate section.

10 9. The ceramic actuator of claim 5 formed from a
continuous sheet of piezoelectric material.

10. Method for manufacturing an actuator in accordance
with claim 5, comprising the steps of
15 - manufacturing deformable sheets of pre-cursor
material;
- applying a first, a second and a third electrode
onto the sheets;
- stacking said sheets such that at least one first,
20 second and third electrode overlay to form a layer of
bimorph tape;
- pressing the bimorph tape into the shape of the
actuator; and
sintering the shaped tape, wherein two of the three
25 electrodes have gaps at locations corresponding to
areas between adjacent sections of the actuator and
one of the three electrode is continuous across the
areas.

30 11. The method of claim 10, further comprising the step of
poling straight sections of the actuator opposite to
the arcuate section.

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ABSTRACT

A loudspeaker for audible sound and a drive unit are described having a sound-emitting element mounted onto a support structure and a U-shaped ceramic actuator made of piezoelectric material.

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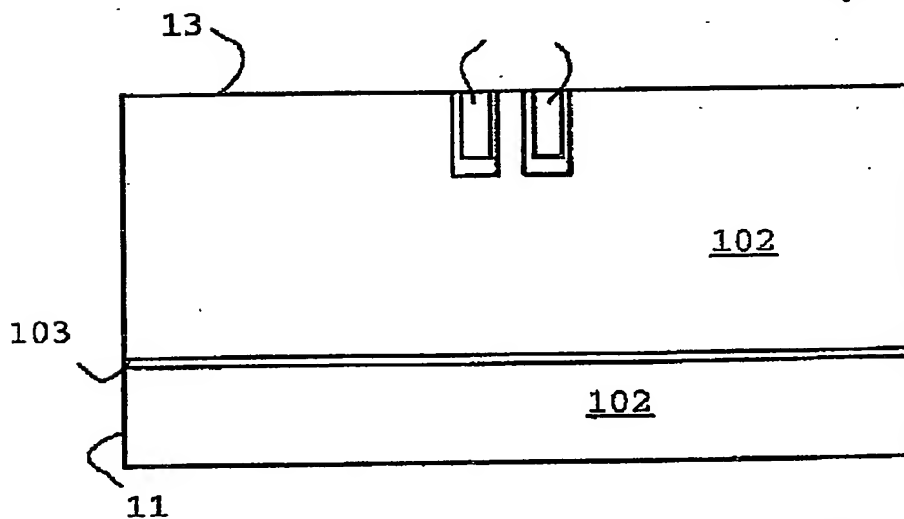
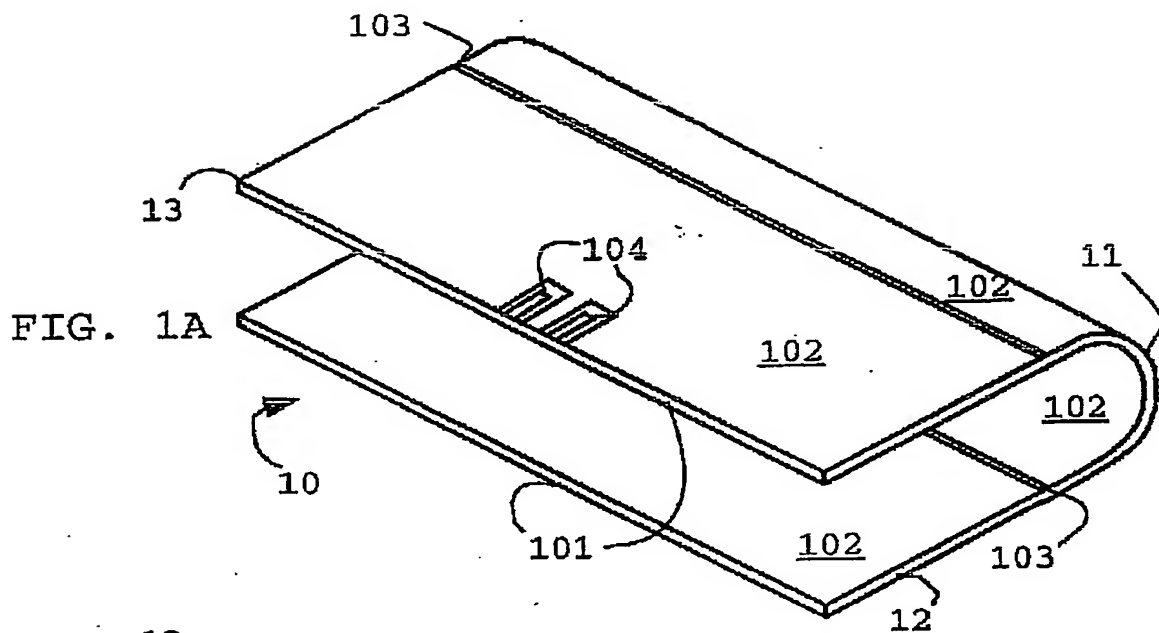
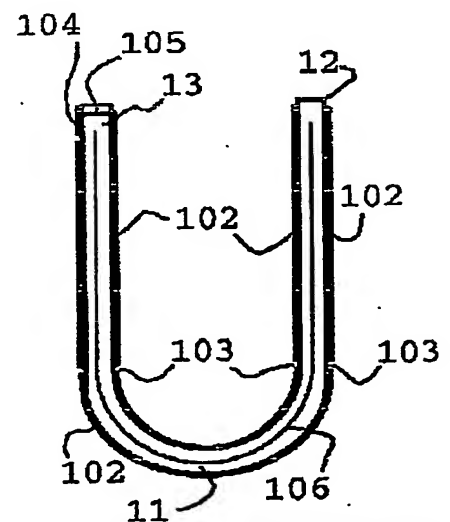


FIG. 1C



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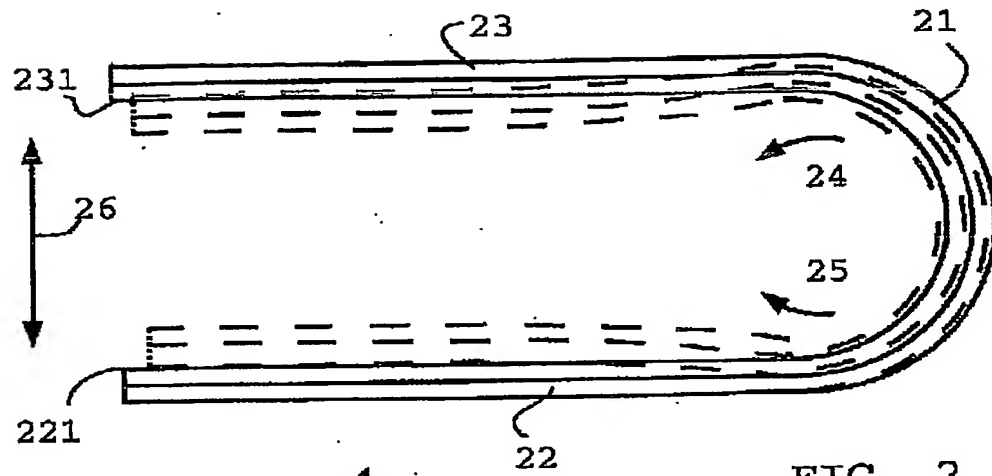


FIG. 2

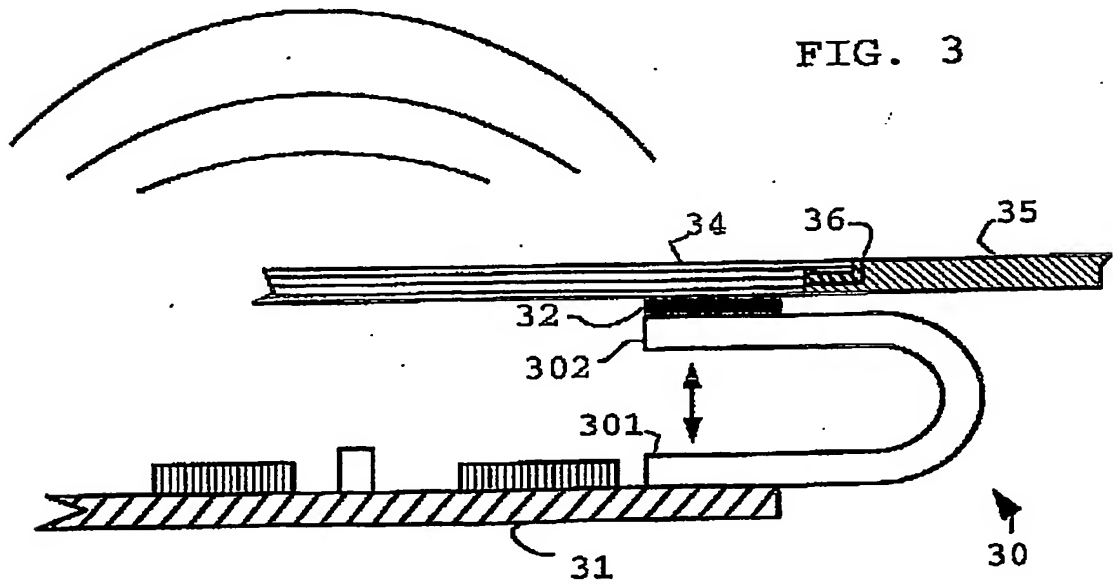


FIG. 3

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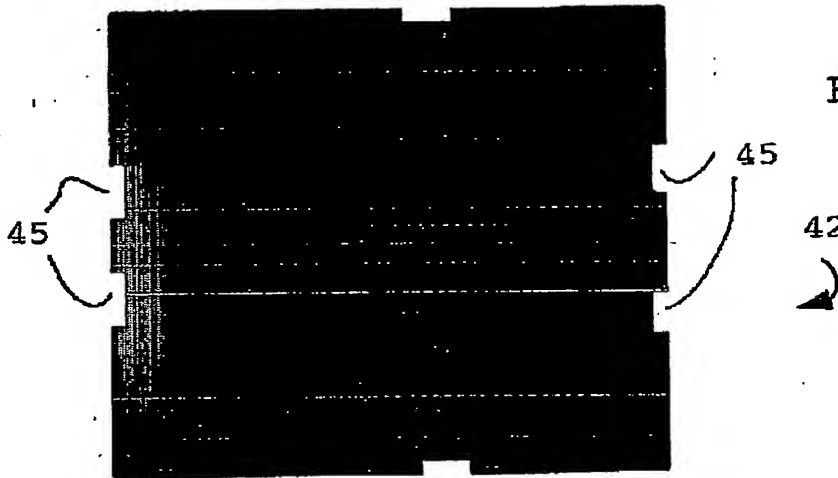
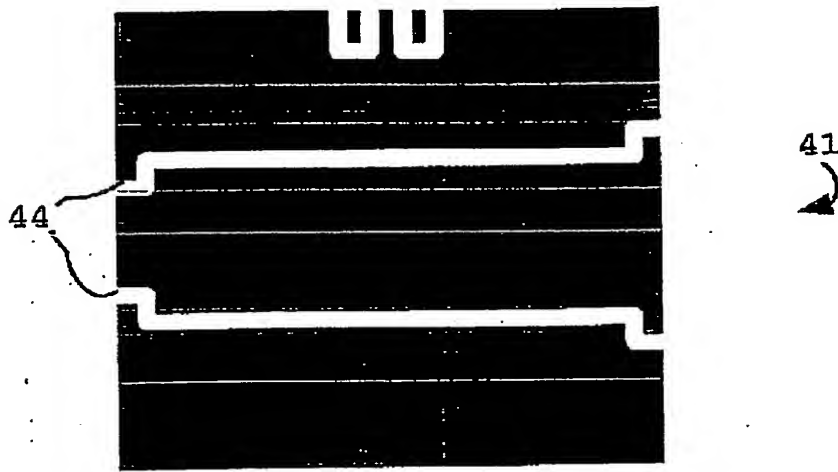
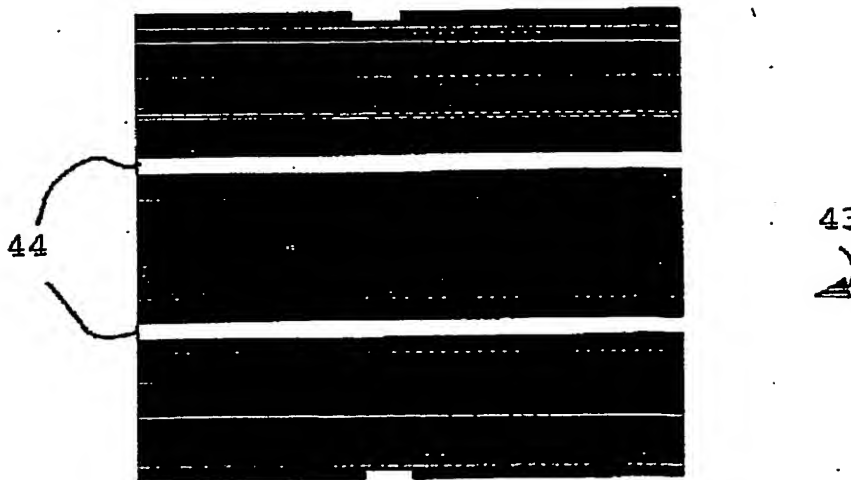
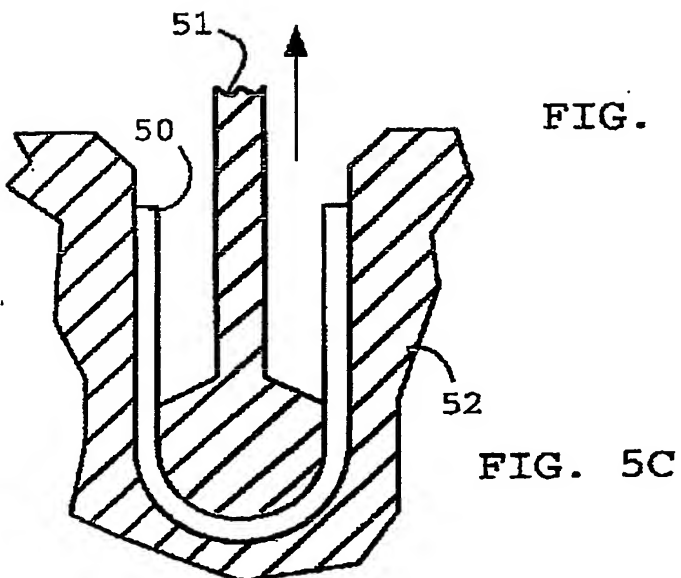
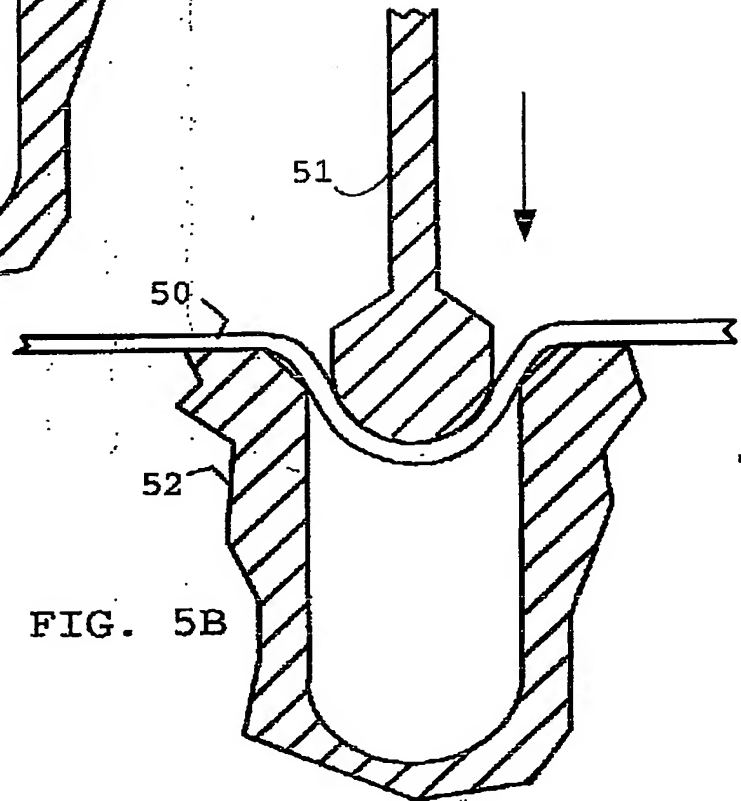
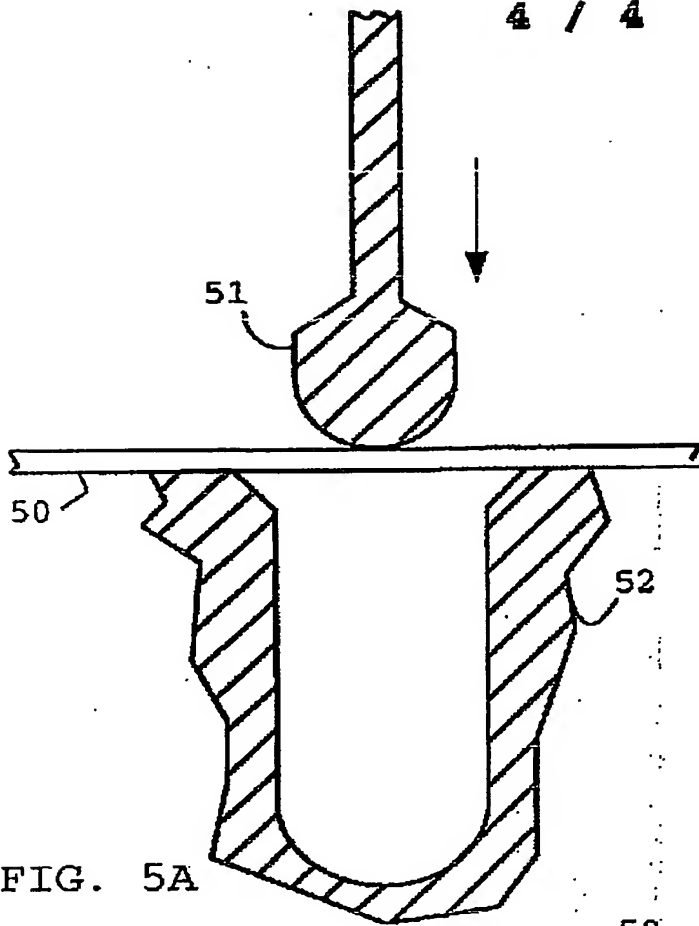


FIG. 4



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